AD

TECHNICAL REPORT ARCCB-TR-97003

WIRE EDM FATIGUE STUDY WITH APPLICATION TO MULTI-LUG BREECH MECHANISMS

V. J. OLMSTEAD
S. TAUSCHER

JANUARY 1997

US ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC QUALITY INSPECTED 3

19970414 052

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

The use of trade name(s) and/or manufacturer(s) does not constitute an official indorsement or approval.

DESTRUCTION NOTICE

For classified documents, follow the procedures in DoD 5200.22-M, Industrial Security Manual, Section II-19 or DoD 5200.1-R, Information Security Program Regulation, Chapter IX.

For unclassified, limited documents, destroy by any method that will prevent disclosure of contents or reconstruction of the document.

For unclassified, unlimited documents, destroy when the report is no longer needed. Do not return it to the originator.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response including the time for reviewing instructions searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington DC 20503

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1997	Final

4. TITLE AND SUBTITLE
WIRE EDM FATIGUE STUDY WITH APPLICATION TO MULTI-LUG BREECH MECHANISMS

5. FUNDING NUMBERS
AMCMS No. 6226.24.H180.0
PRON No. W16H1F531

6. AUTHOR(S)
V.J. Olmstead and S. Tauscher

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Benet Laboratories, AMSTA-AR-CCB-O
Watervliet, NY 12189-4050

8. PERFORMING ORGANIZATION REPORT NUMBER
ARCCB-TR-97003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army ARDEC
Close Combat Armaments Center
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A fatigue study was conducted to evaluate wire electrical discharge machining (EDM) as a manufacturing method for the production of the intricate lug geometry on multi-lug breech mechanisms. The wire EDM process produces a thin surface layer of recast material that was found to have an adverse effect on specimen fatigue life. Removal of the recast layer is recommended on highly stressed critical components.

Unidirectional bending fatigue tests were performed utilizing notched rectangular test specimens made from ASTM A723 steel material. The fatigue tests compared wire EDM prepared surfaces to those produced by the conventional drilling and honing process. The effects of multiple EDM passes and post-processing techniques such as bead blast cleaning, shot peening, and mechanical overloading were investigated.

The recast layer was found to have a significant detrimental effect on specimen fatigue lives. Fatigue life reductions of 20 to 40 percent were observed. The deleterious effect on fatigue increases as the applied stress decreases. The post-processing techniques improved lives but they were generally inferior to those that were conventionally machined and treated with the same process. In limited testing, the combination of glass bead cleaning and mechanical overloading provided "significant" improvement in life compared to either process applied individually.

14. SUBJECT TERMS	15. NUMBER OF PAGES
EDM Recast Layer, Fatigue, Glass Bead Clean, Gun Steel, Multi-Lug Breech Mechanisms, Overload, Shot Peen, Wire EDM	29
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

DTIC QUALITY INSPECTED 3

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ACKNOWLEDGMENTS

The authors wish to extend their appreciation to the following personnel of Benet Laboratories: Mr. T. Sage for his diligent effort conducting the fatigue tests; Ms. L. Bohojckeek and Ms. R. Tedesco for their metallographic work; Mr. D. Kosinski for the strain gaging measurements; and Mr. F. Pfindl for fabricating the fixtures.

INTRODUCTION

Today's emphasis on high-performance, lightweight, durable cannon designs was the impetus for the development of the multi-lug breech mechanism. This design is characterized by a series of modified buttress threads or lugs at the ring-block interface as illustrated in Figure 1. This design is stress-efficient and is achieved through the use of generous fillet radii and accurate control of parameters such as lug size, location, and interface angles. The mechanism's fatigue life is further enhanced by the use of compressive surface residual stresses in the lugs and fillet radii. The beneficial residual stresses in prototype breech mechanisms were initially produced by the shot peening technique; however, more recently an overload process is being used to produce a deeper residual stress field.

The multi-lug geometry is very costly to manufacture due to its complexity and the accuracy required. Conventional manufacturing methods include gun drilling, milling, and broaching the breech ring and milling and grinding the block. These manufacturing methods require a significant investment in tooling, fixturing and set-up time. Travelling wire electrical discharge machining (EDM) is a modern manufacturing method that has potential to produce the multi-lug configuration on breech rings and blocks. For development and prototype work, the wire EDM process offers flexibility by allowing for rapid configuration changes without retooling. This is easily accomplished by altering the computer-generated numerical control program that directs the path of the wire cut. For production work, the process can produce very accurate and repeatable dimensions, provided the material has been well stress-relieved and excess material is removed. Wire EDM machines can also be economical to operate because they can run unattended for up to 75% of the total cutting time.

The major concern with the wire EDM process is the surface integrity of the work piece. Wire EDM is a thermal machining process. Localized material is melted and vaporized due to the heat generated by the impingement of electrical sparks emitted by the EDM machine. The surface produced by the wire EDM process consists of a recast layer composed of melted and resolidified material. This hardened recast layer is extremely thin, but even so, it can have an adverse effect on the fatigue strength of the material.[1]

The objective of this investigation was to determine the effect of the wire EDM process on fatigue characteristics of an ASTM A723-type high-strength alloy steel utilized in the manufacture of breeches. More specifically, the following questions were addressed.

- To what degree does the wire EDM process degrade the fatigue life of A723-type high-strength, quenched and tempered steel?

- When very accurate dimensions, tight tolerances, and fine surface finishes are required, multiple wire EDM passes are generally required. Does a wire EDM finishing pass, which is relatively low powered, improve the fatigue resistance compared with the higher powered EDM roughing pass?

- Glass bead blast cleaning is frequently used after the wire EDM process to improve the appearance of the finished surface. Does this relatively light peening process have any effect on fatigue life?

- Shot peening creates residual compressive stresses near the surface, which delay crack initiation and increase total life. Does the relatively intensive steel shot peening operation remove the recast layer and restore the level of fatigue resistance to those of conventionally machined surfaces that have also been shot peened?

- Mechanical overloading of components where plastic straining occurs results in the introduction of favorable residual stresses, which generally improve fatigue life. Does mechanical overloading provide the same benefits for a surface that has undergone the wire EDM process compared with a conventionally machined surface and does glass bead cleaning prior to overloading alter the results?

APPROACH

The approach used was to compare the crack initiation and total fatigue lives of bend beam test specimens that were prepared and described in the section below called "Notch Conditions." To reduce the effects of material lot-to-lot variation, all of the specimens were manufactured from a single forging of A723-type alloy steel material. Rectangular test specimens were utilized that had a semi-circular notch to concentrate the stress and control the location of crack formation. The three-point bend specimens were fatigued using two different unidirectional bending loads. Details of the specimen design, material, notch conditions, and test procedures are described below.

Specimen Design

The specimens had a rectangular configuration with dimensions of 1" H x ½" W x 5" L. Each specimen had a semi-circular notch with a 0.25-inch radius that was located on the narrow edge midway along the 5-inch dimension. The specimens were unidirectionally loaded in three-point bending as represented in Figure 2. The four drilled and tapped holes were utilized to locate and attach the screw-type knife edges for mounting the clip-on displacement gage.

Two techniques were employed to determine the stress concentration effect of the semi-circular notch geometry. Experimental strain measurements were obtained from strain gages that were applied to the mid-section of the notches on four test specimens. During strain gaging, a series of increasing loads was applied and released, which produced applied strains well into the plastic region. The applied and permanent notch strain results for specimen C12 were typical and are shown in Figure 3. The theoretical stress concentration factor was determined by performing an elastic finite element (FE) analysis on the specimen geometry utilizing the I-DEAS Master Series 2.0 modeling software (Structural Dynamics Research Corporation). The elastic stress concentration factor, K_t, was determined to be 1.62. As shown in Figure 3, the elastic strain predicted by the FE analysis agrees favorably with the elastic portion of the applied strain curve.

Material

All of the specimens were manufactured from a single EX35 breech ring forging. This material was procured to the steel forging specification MIL-S-46119. Chemical analysis and mechanical property tests were performed on this material, and the results are shown in Tables 1 and 2, respectively. The specimens were laid out in the forging such that the forging flow lines were parallel to the major axis of the specimens. The notch fillets were oriented toward the breech ring recess opening. The layout of the test specimens in the breech ring forging is shown in Figure 4.

Notch Conditions

The list below summarizes the 10 test conditions that were prepared and fatigue tested:

- Drilled and honed
- Drilled and honed plus shot peened
- Drilled and honed plus overloaded
- Wire EDM - one pass
- Wire EDM - two passes
- Wire EDM - two passes plus glass bead-cleaned
- Wire EDM - two passes plus shot peened
- Wire EDM - two passes plus overloaded
- Wire EDM - two passes plus glass-beaded plus overloaded
- Drilled and honed plus glass-beaded plus overloaded.

The breech ring fillets are currently produced by a deep-hole gun drilling operation followed by either a whipping or honing operation to improve the surface to at least a 63-RMS finish. The notches on the conventionally machined test specimens were likewise produced by drilling. Pairs of specimens were clamped together, drilled, and then finished by either whipping or honing to achieve the 63-RMS surface finish.

The wire EDM notch radii were cut one at a time (specimens were not stacked) using a Japax Model LDMS wire EDM machine. An Inteck 0.010-inch diameter brass wire electrode was used for all the cuts. The dielectric fluid was deionized water. The machine parameter settings for the first cut were as follows:

- Time on: 8
- Time off: 7
- Peak current: 7
- Voltage setting: 8
- Feed rate 0.040 inch per minute.

Most of the specimens received a second finishing pass that was programmed to remove another 0.0003 inch. The machine parameters for the second pass were:

- Time on: 5
- Time off: 6
- Peak current: 6
- Voltage setting: 7
- Feed rate 0.100 inch per minute.

The specimens requiring shot peening were sent to Metal Improvement Company, Windsor CT. The requirements were to shot peen using a shot size of 330, with an intensity of 0.006C to 0.008C per MIL-S-13165. This requirement was selected because it is frequently called out on ordnance components made from high-strength alloy steel. The specimens were processed as a single batch using steel shot size 330 (0.033-inch diameter) to obtain 100% coverage, with an actual intensity range of 0.0065C to 0.007C, which was verified by the starting and ending Almen test specimens.

The specimens requiring glass-bead blasting were cleaned in a dry suction-feed type abrasive blasting system. The spherical glass media were U.S. standard screen size: 50/70 (0.008 to 0.012 inch). The air pressure was 100 psi. The exposure time was estimated to be 45 to 60 seconds. The nozzle stand-off distance was approximately 3 inches.

The overload consisted of applying a one-cycle bending load in the same direction as the subsequent fatigue load and of sufficient magnitude to produce localized yielding in the specimen notch. Upon release of the overload, the specimen unloads in an elastic manner, which places the notch surface in a state of compression. The overload used in these tests, P_{ov}, was 9,000 lb. The overload ratios for these fatigue tests, P_{ov}/P_{max}, at the high and low loads were 1.12 and 1.63, respectively.

As expected, the various processes used to prepare the notch radii produced different surface finishes. The surface finishes in the notch radii regions were measured on representative test specimens, and the results are shown in Table 3. The finish along the width direction and parallel to the axis of notch radii was measured using a Federal Products Surf-indicator. The indicator requires a flat surface and could not be used to measure the curved surface in the circumferential direction. The surface finish in this direction was obtained by using visual comparison blocks.

Testing Procedure

The test specimens were fatigue-cycled at 5 Hz on a 55-kip MTS servo-controlled electrohydraulic testing machine. A fixture was designed to load the specimens in three-point bending. The fixture minimized frictional effects by allowing the support rollers to rotate slightly when the specimens were loaded. This fixture is shown in Figure 5. All testing was conducted in a load control mode; therefore, specimen failure occurred relatively soon after crack initiation was established. The crack initiation in this fatigue study was defined when a predetermined increase in mouth-opening displacement was measured using an MTS clip-on displacement gage. The displacement criteria were established during preliminary testing. The size of the initial cracks was determined by heat tinting the specimens at 375°F for 2 hours. The heat tinting formed an oxide on the initiation fracture surfaces, which provided a visual means to determine their size once the specimens were totally fractured. The singular and multiple initiation cracks were typically elliptical shaped. Their total area represented approximately 1% of the total fracture area.

The specimens were tested using a load ratio of $R = 0.1$ at one of two test load ranges, either the low load range from 550-lb minimum to 5,500-lb maximum, or the high load range from 800-lb minimum to 8,000-lb maximum. The loading ranges were selected based on prior testing, which generated failures in the low-cycle regime.[2] The high and low loads produced fatigue lives in the drilled and honed specimens that bracket the lives measured in laboratory fatigue tests conducted on prototype breech mechanisms.

RESULTS

The test data for the various tests conducted at both the low and high test loads are listed in Tables 4 and 5, respectively. The average initiation, total, and propagation lives, as well as the standard deviations, are based on the average of six test replications unless otherwise annotated. The propagation lives were calculated by averaging the individual differences between the total and initiation lives. To determine whether a significant difference exists between the results, statistical analyses were performed using the "Student's" t test.[3] The two tailed tests were applied using the 99% confidence limit. The results of the analyses for the total life data are summarized in Table 6. The analysis was also performed on the initiation data (not shown), and no change was found in the column "Significant Difference (Yes/No)."

The results as they relate to the five objectives in the introduction are discussed below.

Effect of Wire EDM

A graphical comparison of the average fatigue lives for the wire EDM and the drilled and honed test specimens is shown in Figure 6. The ratio of the average total life of the EDM (double-pass) test compared with that of the drilled and honed life is: $N(t)_{EDM}/N(t)_{D\&H} = 0.63$ at the low-load range and $N(t)_{EDM}/N(t)_{D\&H} = 0.80$ at the high-load range. The ratio of initiation lives provides similar results: $N(i)_{EDM}/N(i)_{D\&H} = 0.60$ and 0.74 at the low and high ranges, respectively. At the low-load test range, the differences in both the initiation and total lives were found to be statistically significant. At the high-load test range, there was no statistically significant difference primarily due to the large standard deviation that exists in the drilled and honed data.

Effect of Second EDM Finishing Pass

The results of the fatigue test show no significant difference between the lives of the single-pass specimens compared with those finished with a second pass. A graphical comparison of the results is again shown in Figure 6. Samples of the test specimens were mounted, polished, etched, and then examined using a metallurgical microscope. The recast layer on the single-pass specimens has a thickness that varied from 0.0001 to 0.0006 inch and an average thickness of 0.0002 inch. This compares to the double-pass specimens, which varied between 0.00005 and 0.0003 inch with an average thickness of 0.0001 inch. The profile of the recast layer resembles a series of wave crests (see Figures 7a and 7b) and is probably due to slight changes in wire travel speed. The recast layer was too thin to obtain reliable hardness measurements, but its microstructure is consistent with that of a hard and brittle untempered martensite. The presence of any heat-affected zones beneath the recast layer was checked using microhardness profiles on the specimen cross-sections using a Knoop Indentor with the 100-gram load. A reduced hardness region, approximately 0.002 inch deep, was found to exist on both the single and multiple EDM specimens. The wire EDM process appears to generate enough heat to overtemper a thin layer of the material just beneath the hard recast layer.

Effect of Glass-Bead Cleaning

The glass-bead-cleaned wire EDM specimens provided some surprising improvements in fatigue lives. The level of improvement between the wire EDM and the drilled and honed specimens can be seen visually in Figure 8. There is a statistically significant difference between the EDM specimens with and without glass-bead cleaning at both the low and high loads. Based on the average total life data, the bead-cleaned specimens compared with the unbeaded ones, had an average life increase of 170% at the low load and a 60% increase at the high load.

Samples of the glass-beaded specimens were prepared for metallographic examinations. The examinations revealed that the recast layer was not eliminated by the blast cleaning process. The glass-bead cleaning reduced the thickness slightly and improved the overall thickness uniformity (see Figure 9). Since the recast layer was not totally removed, the improvement in fatigue life is attributed to the combination of surface finish improvement and the favorable residual peening stresses produced by the glass-bead cleaning process.

Effect of Shot Peening

Shot peening provided for a statistically significant improvement in specimen fatigue lives in all cases, except for the drilled and honed specimens subjected to the high load. A graphical comparison of the improvements provided by shot peening is shown in Figure 10. At the low load, the shot peening doubled the total average life of the EDM specimens, while it increased the total life of the drilled and honed specimens by a factor of 1.6. At the high load, shot peening improved the life of the EDM specimens by 17%, while no improvement was observed with the drilled and honed specimens. A life comparison between both types of shot-peened specimens indicates no difference at the high load, while the average life of the EDM specimens was 79% that of the drilled and honed specimens. The statistical analyses at the 99% confidence level showed no significant difference in the lives of the two types of shot-peened specimens.

A photomicrograph of a cross-section of a typical shot-peened specimen is shown in Figure 11. This figure shows the recast layer is still present. The thick wave crest areas are gone. Laps in the recast surface are visible and appear to be sites where the wave crests were peened flat.

One anomaly was observed when comparing the glass-beaded and the steel shot-peened EDM results. The glass-beaded specimens outperformed the shot-peened ones at the high-load condition. This is surprising because the large steel shot produces a greater depth of compressive stress compared with the smaller glass shot. Two contributing factors to this condition may be the coarser surface roughness (see Table 3) and the presence of the laps observed in the peened recast layer surface.

Effect of Overloading

A comparison of the average fatigue lives for overloaded and non-overloaded specimens is shown in Figure 12. At the low load, the overloaded EDM specimens had increased lives relative to the EDM ones with no residual stress. However, the lives were inferior relative to those of the drilled and honed specimens with overload residual stresses. It is interesting that the fatigue life ratio of the wire EDM to the drilled and honed specimens was 0.63 for both the overloaded and non-overloaded conditions. This observation suggests that the recast layer, if allowed to remain on the surface, will generally have a similar detrimental effect relative to non-EDM surfaces regardless if residual stresses are present or not. At the high load, no statistical difference was observed between the overloaded and non-overloaded specimen lives for either the EDM or the drilled and honed specimens. The lack of observed improvement in fatigue lives at the high load is likely due to the relatively small overload ratio ($P_{ov}/P_{max} = 1.12$) for these tests.

After observing the significant improvement in lives for both the glass-bead-cleaned and the overloaded specimens, tests were conducted to determine the effect of incorporating both processes together. Three EDM (double-pass) and three drilled and honed specimens were prepared by bead blast cleaning followed by a single cycle overload at 9,000 lb. The specimens were then cycled at the low-load range (550 to 5,500 lb). The six tests were stopped at 600,000 cycles each, with no failures or cracks observed. One of the specimens was cycled an additional 400,000 times, and still no cracks were observed. These results suggest that a positive reinforcement of beneficial residual stresses occurs when the two processes are combined. The effect may be sensitive to the processing sequence, type of peening media, peening intensity, overload magnitude, and overload ratio. This area is beyond the scope of work of this project, but it certainly warrants further study.

CONCLUSIONS

1. The recast layer produced by the wire EDM process has a significant detrimental effect on the fatigue lives of A723 alloy steel test specimens compared with those prepared using a conventional machining process. Fatigue life reductions of 20% to 40% were observed in the fatigue tests.

2. The deleterious effect on fatigue life due to the recast layer increases as the applied stress decreases.

3. A reduction in the recast layer thickness by incorporating a finishing EDM pass has no apparent effect on fatigue life.

4. Glass-bead cleaning and shot peening processes did not remove the recast layer on the test specimens.

5. Glass-bead cleaning does more than cosmetically improve the EDM surface; it can significantly improve the fatigue life.

6. Peening or overloading an EDM surface improves the component fatigue life, but the life is generally inferior to a conventionally machined component that has been peened or overloaded.

7. In limited testing, the combination of glass-bead cleaning followed by overloading has demonstrated "significant" increases in fatigue life compared with either glass-bead cleaning or overloading processes applied individually.

RECOMMENDATIONS

1. In critical applications (*e.g.*, breech mechanisms) where high tensile stresses are anticipated and maximum fatigue life is desired, remove the EDM recast layer by gentle machining.

2. For less critical applications where moderate tensile stresses are anticipated, use a glass-bead cleaning process to peen the EDM surfaces.

3. Conduct further testing and investigation of combining the peening and overloading processes together to enhance fatigue life. Initial test results were promising, but more investigation is recommended before utilizing this process on critical components.

REFERENCES

1. *Metals Handbook,* 9th Edition, "Machining," American Society for Metals, Metals Park, OH, Vol. 16, 1989, pp. 31-36.

2. Farrara, R. and Underwood, J. H., "The Effect of Manganese Phosphate Coatings on Fatigue Crack Initiation," ARDEC Technical Report ARCCB-TR-90018, Benet Laboratories, Watervliet, NY, June 1990.

3. Spiegel, M.R., *Theory and Problems of Statistics,* Schaum Publishing Co., New York, NY, 1961, pp. 189-190.

Table 1. Chemical composition of alloy steel forging per Mil-S-46119

Element	Specified (%)	Actual (%)
C	0.40 Max	0.342
Mn	0.30/0.80	0.641
Si	0.35 Max	0.162
P	0.025 Max	0.005
S	0.025 Max	0.009
Ni	2.00/3.25	2.592
Cr	0.70/1.20	1.041
Mo	0.30/0.50	0.445
V	0.15 Max	0.090
Cu	-	0.092

Table 2. Mechanical properties (average of two tests)

Mechanical Property	Specified Transverse	Actual	
		Transverse	Longitudinal
Yield Strength 0.1% Offset (Ksi)	150/170	164.2	162.5
Ultimate Strength (Ksi)	-	180.5	178.5
Reduction in Area (%)	30/25	34.9	57.6
Elongation GL:4D (%)	-	13.2	16.9
Charpy Impact (ft-lb @ -40°F)	20/15	18.0	29.5

Table 3. Notch surface finish

Notch Radius Finishing Process	Surface Finish (micro-inches)	
	Transverse Direction Method: Indicator	Circumferential Direction Method: Visual
Drilled and Honed	30-35	32
Drilled and Whipped	123-135	32-63
Wire EDM (Single-Pass)	70-80	125
Wire EDM (Double-Pass)	45-50	63
Glass-Bead Blasted	45-50	45-50
Steel Shot Peened	100-125	100-125

Table 4. Effect of finishing process on specimen fatigue life - low load

Surface Condition	Initiation Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)	Total Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)	Propagation Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)
Drilled and Honed	52,429 (4 ea)	8,405	62,265 (4 ea)	8,139	9,835 (4 ea)	735
Drilled and Honed plus Shot Peened	95,611 (5 ea)	18,149	100,329	21,084	10,844 (5 ea)	2,116
Drilled and Honed plus Overloaded	136,771 (4 ea)	24,250	148,474 (4 ea)	23,433	11,703 (4 ea)	831
Wire EDM (Single-Pass)	32,971	2,165	41,106	2,722	8,135	1,423
Wire EDM (Double-Pass)	31,525	2,798	39,353	2,583	7,828	1,093
Wire EDM plus Glass-Beaded	93,756 (4 ea)	21,388	107,350 (4 ea)	20,907	13,595 (4 ea)	764
Wire EDM plus Shot Peened	66,779	12,418	79,560	12,916	12,782	1,065
Wire EDM plus Overloaded	82,912	10,796	93,520	11,678	10,608	1,721
Wire EDM plus GB plus Overloaded	600,000 + (3ea)		600,000 + (3ea)			
Drilled and Honed plus GB plus Overloaded	600,000 + (2ea) 1,000,000 + (1ea)		600,000 + (2ea) 1,000,000 + (1ea)			

Table 5. Effect of finishing process on specimen fatigue life - high load

Surface Condition	Initiation Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)	Total Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)	Propagation Life Average of 6 tests (Cycles)	Standard Deviation (Cycles)
Drilled and Honed	12,679	3,437	15,380	3,382	2,702	500
Drilled and Honed plus Shot Peened	11,235	1,167	14,285	1,148	3,050	146
Drilled and Honed plus Overloaded	11,084	899	14,551	752	3,466	584
Wire EDM (Single-Pass)	9,323	916	12,177	956	2,854	233
Wire EDM (Double-Pass)	9,421	890	12,381	1,009	2,960	323
Wire EDM plus Glass-Beaded	16,591	946	19,848	889	3,257	675
Wire EDM plus Shot Peened	11,438	1,078	14,569	876	3,131	352
Wire EDM plus Overloaded	10,590	1,147	13,961	1,023	3,372	912

Table 6. "Student's" t distribution test of specimen fatigue data (total life)

Surface Condition	Load Level	Degrees of Freedom (No. of tests - 2)	t (actual)	t(0.995)	Significant Difference
Drilled and Honed vs.	High	10	1.90	3.17	No
Wire EDM (Double-Pass)	Low	8	5.75	3.36	Yes
Wire EDM (Single-Pass) vs.	High	10	0.33	3.17	No
Wire EDM (Double-Pass)	Low	10	1.05	3.17	No
Wire EDM plus Glass-Beaded vs.	High	10	12.42	3.17	Yes
Wire EDM (Double-Pass)	Low	8	7.05	3.36	Yes
Wire EDM plus Shot Peened vs.	High	10	3.66	3.17	Yes
Wire EDM (Double-Pass)	Low	10	6.83	3.17	Yes
Wire EDM plus Overloaded vs.	High	10	2.46	3.17	No
Wire EDM (Double-Pass)	Low	10	10.13	3.17	Yes
Drilled and Honed plus Shot Peened vs.	High	10	0.69	3.17	No
Drilled and Honed	Low	8	3.08	2.90*	Yes
Drilled and Honed plus Overloaded vs.	High	10	0.54	3.17	No
Drilled and Honed	Low	8	6.33	3.36	Yes
Drilled and Honed plus Shot Peened vs.	High	10	0.44	3.17	No
Wire EDM plus Shot Peened	Low	10	1.88	3.17	No
Drilled and Honed plus Overloaded vs.	High	10	1.04	3.17	No
Wire EDM plus Overloaded	Low	8	4.39	3.36	Yes

* t(0.99)

Significant difference = yes if t(actual) > t(0.995)

= no if t(actual) < t(0.995)

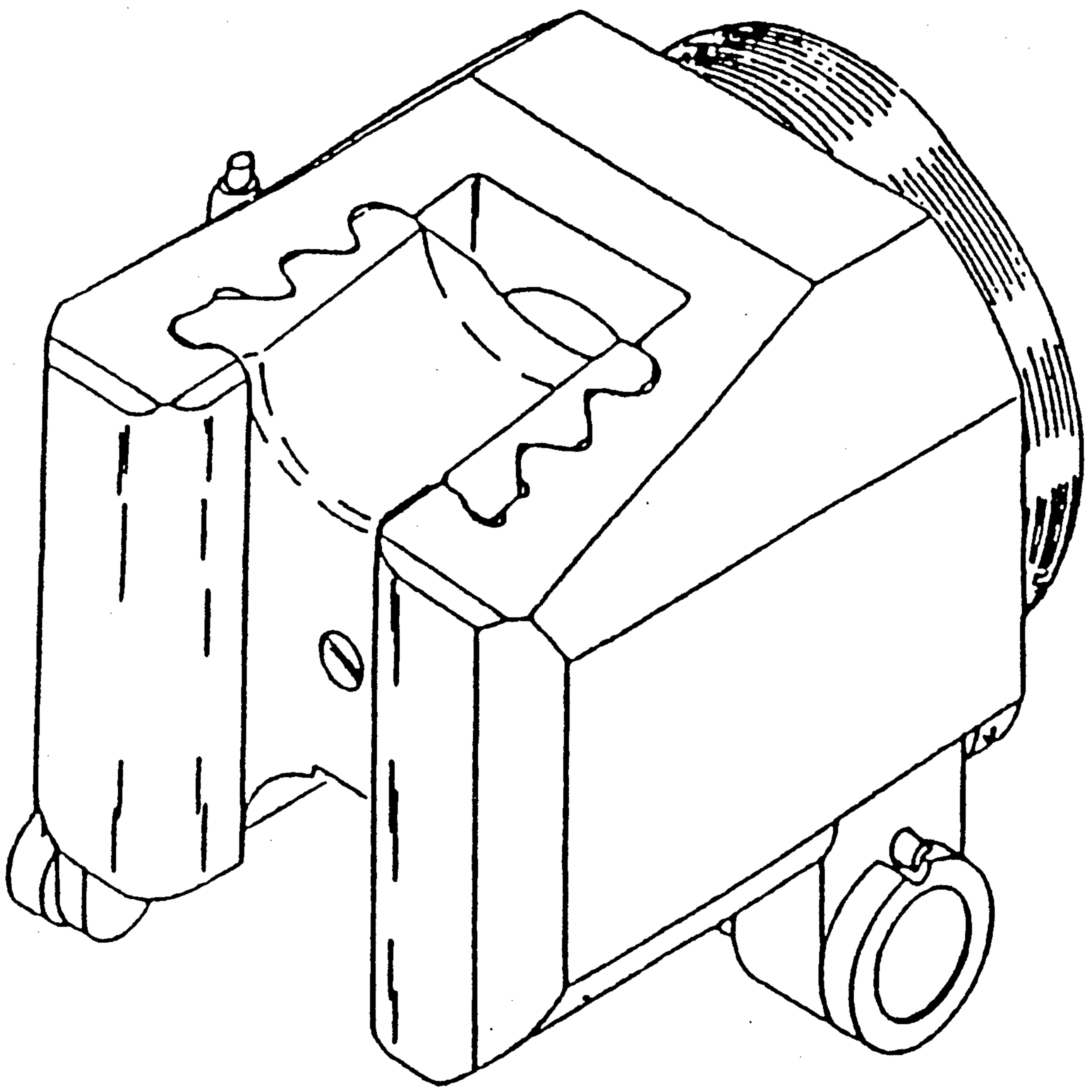


Figure 1. Multi-lug breech ring/block assembly

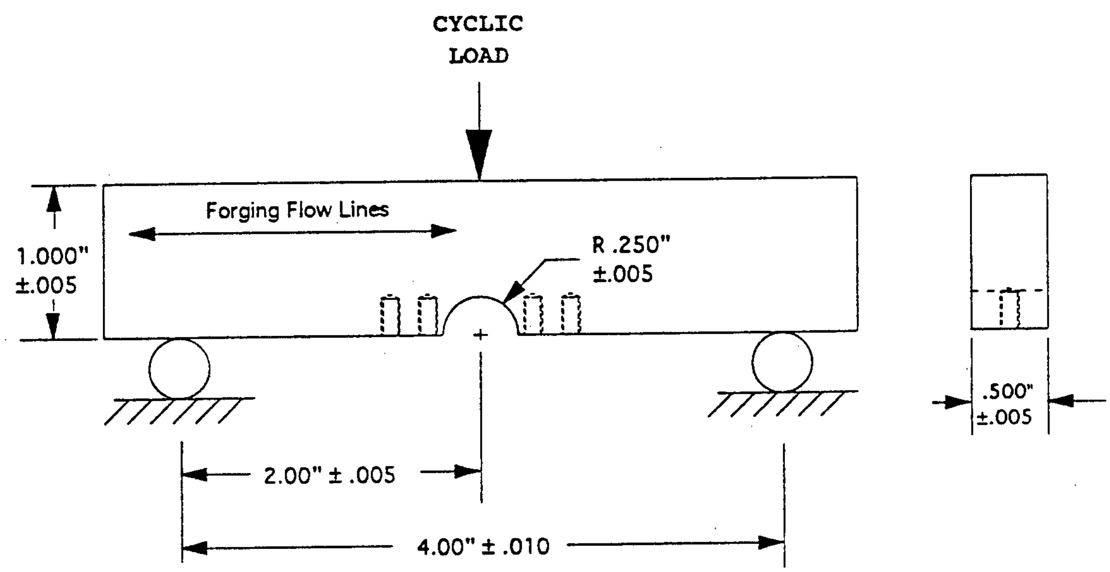


Figure 2. Three-point bend specimen design

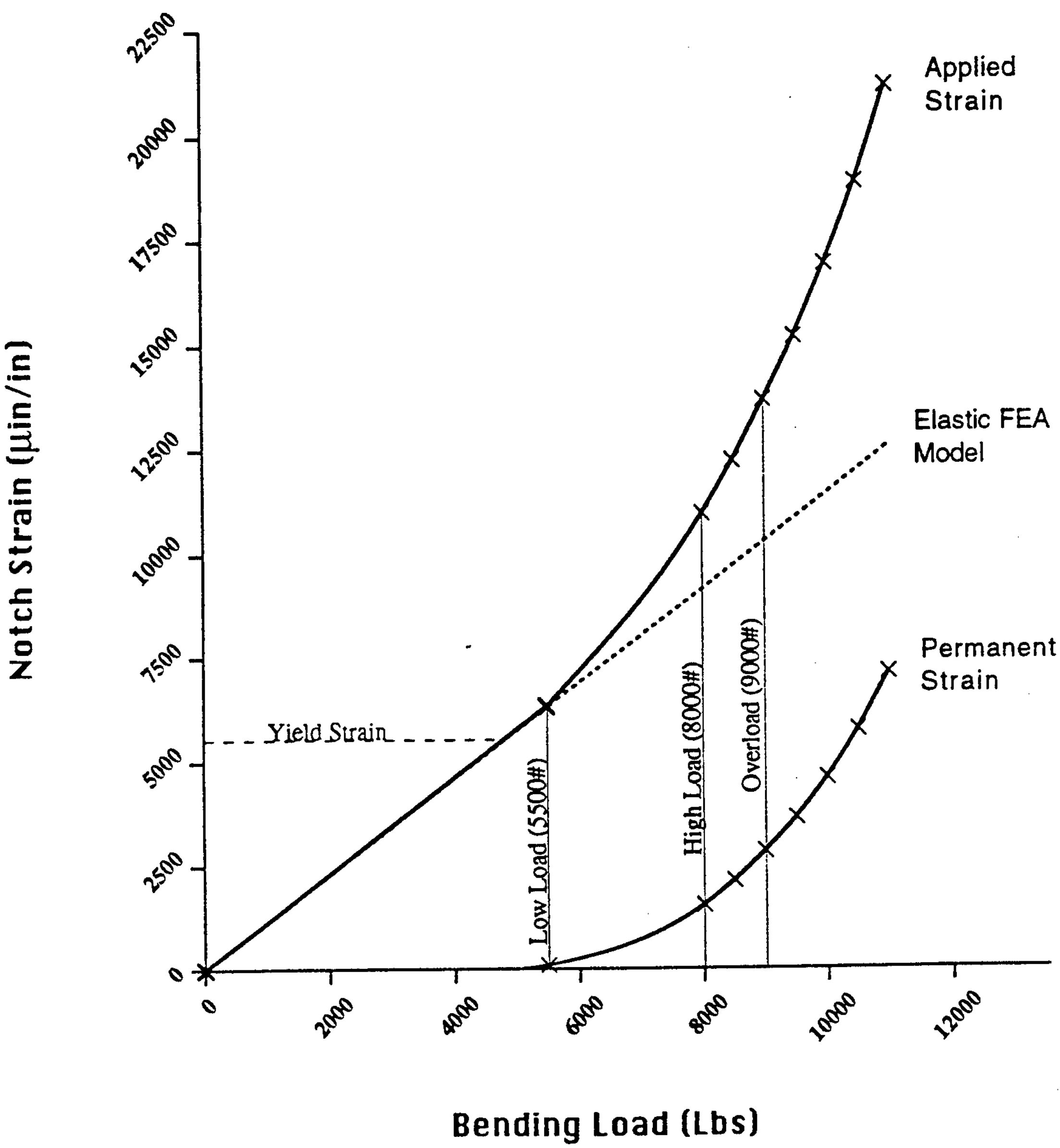


Figure 3. Test specimen notch strain

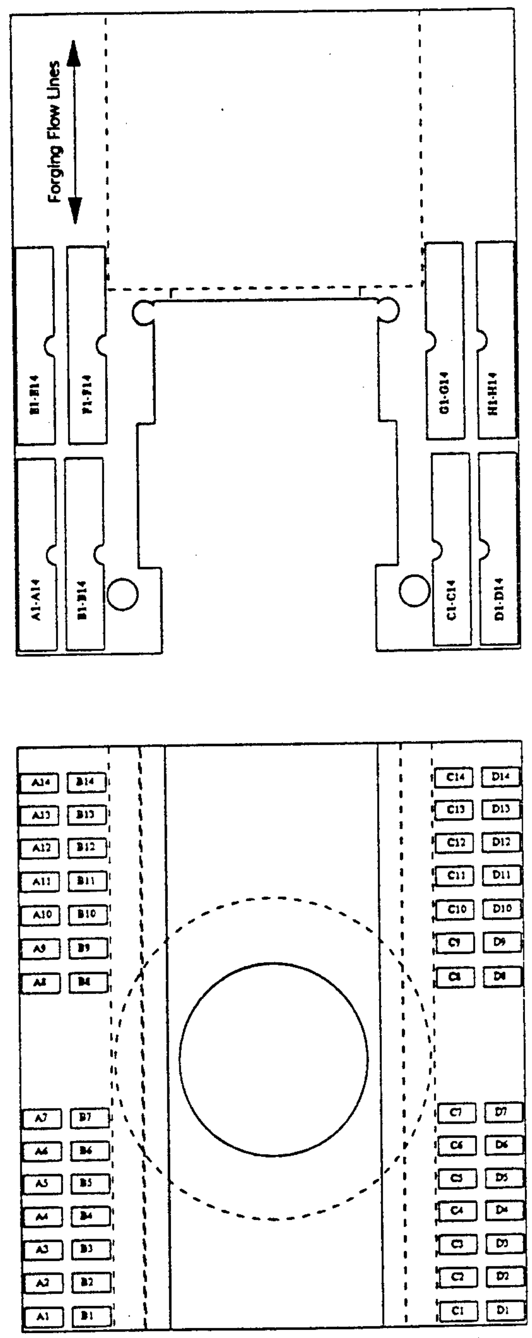


Figure 4. Layout of test specimens in rough machined breech ring forging

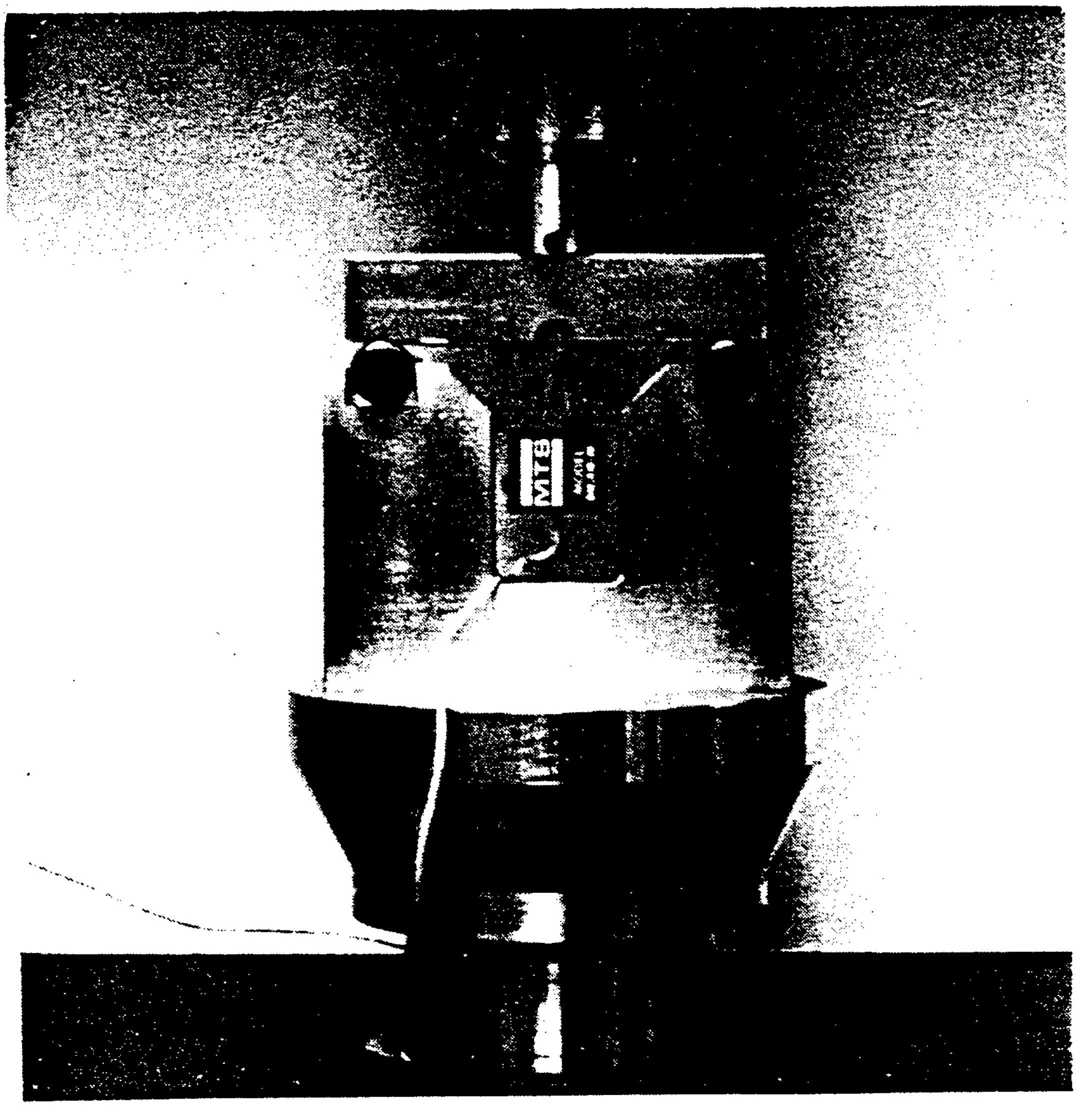
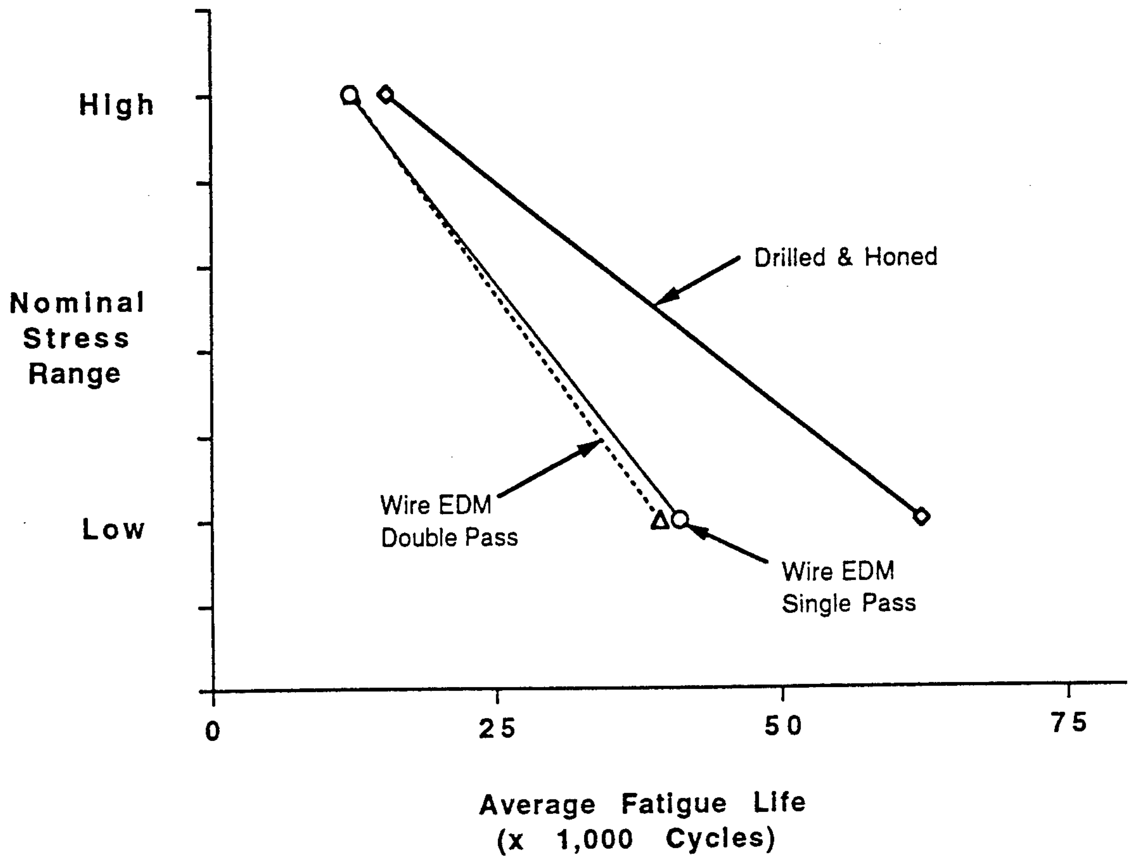


Figure 5. Bend bar fixture used in fatigue tests



Low Nominal Stress Range = 11.7 to 117 Ksi
High Nominal Stress Range = 17.0 to 170 Ksi
Stress Concentration Factor: 1.62

Figure 6. Nominal stress range versus total specimen fatigue life (Comparison of wire EDM and drilled and honed surfaces)

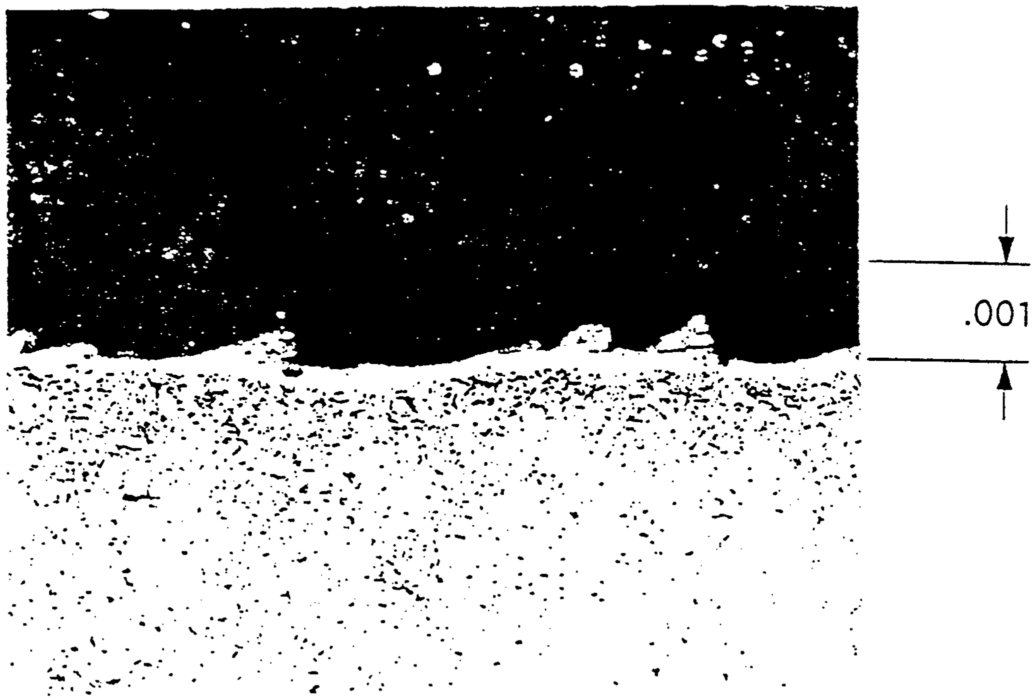


Figure 7a. Wire EDM recast layer - single-pass (magnification 500X)

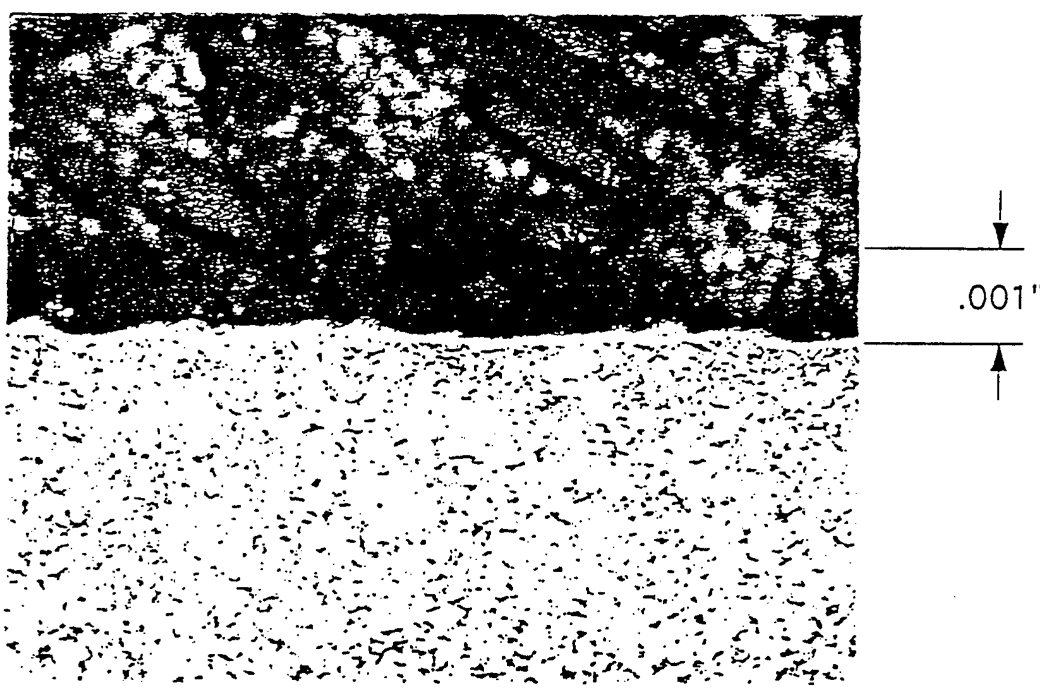
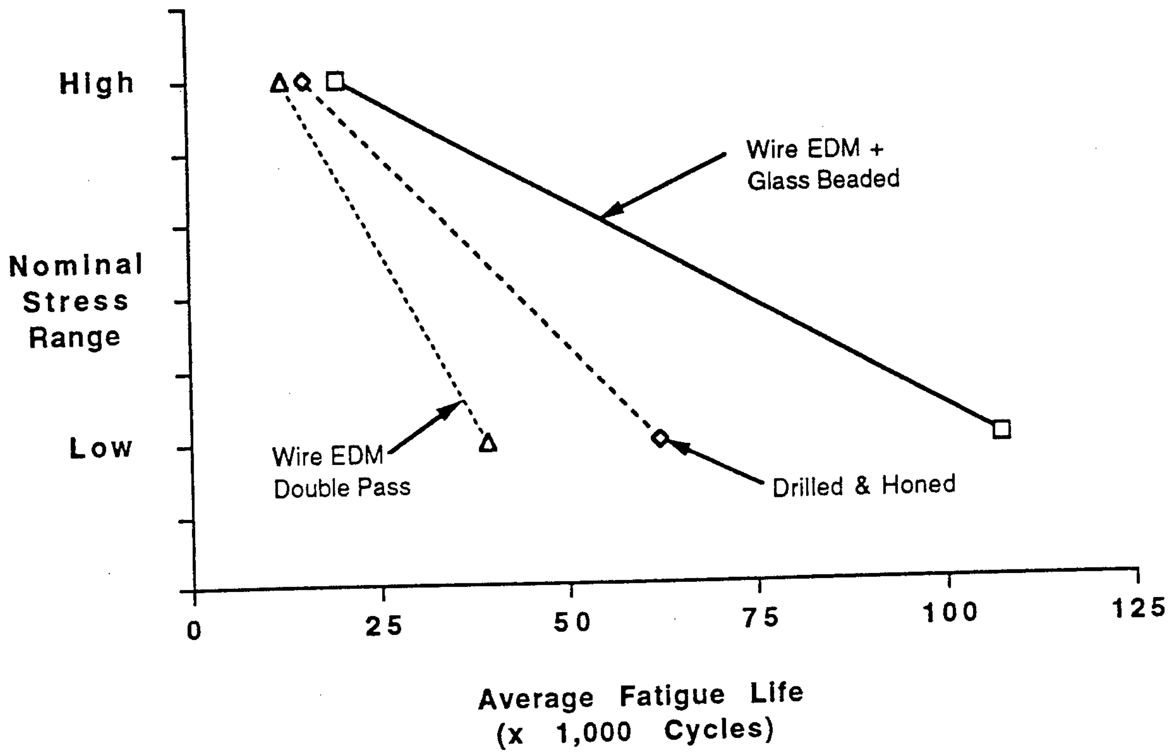


Figure 7b. Wire EDM recast layer - double-pass (magnification 500X)



Low Nominal Stress Range = 11.7 to 117 Ksi
High Nominal Stress Range = 17.0 to 170 Ksi
Stress Concentration Factor: 1.62

Figure 8. Nominal stress range versus total specimen fatigue life (Comparison of wire EDM plus glass-beaded to wire EDM and drilled and honed surfaces)

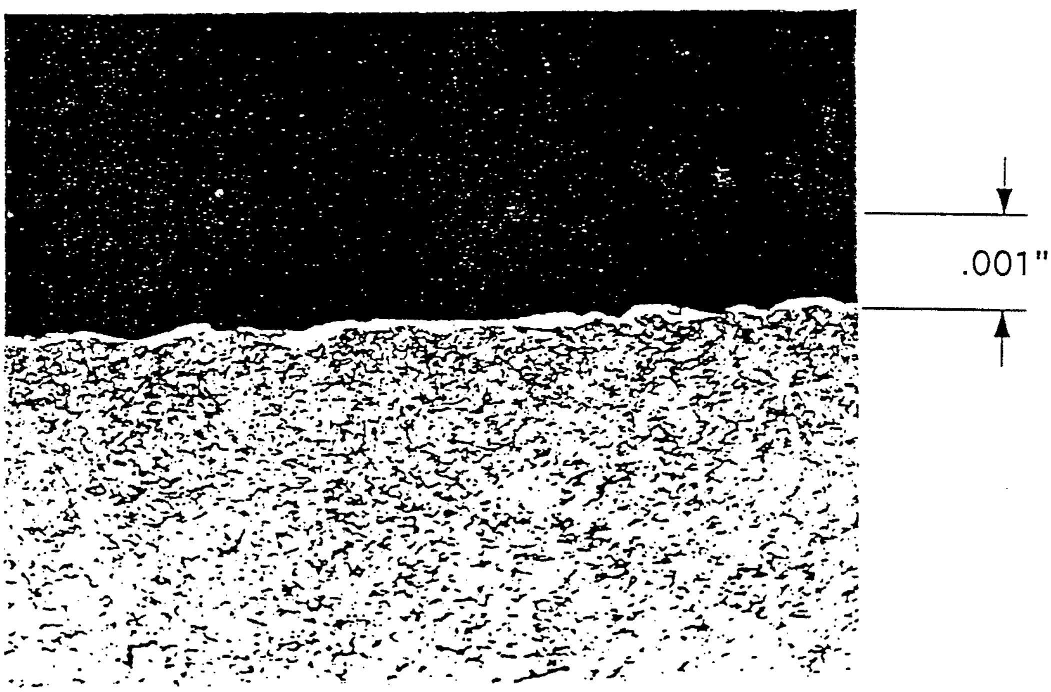
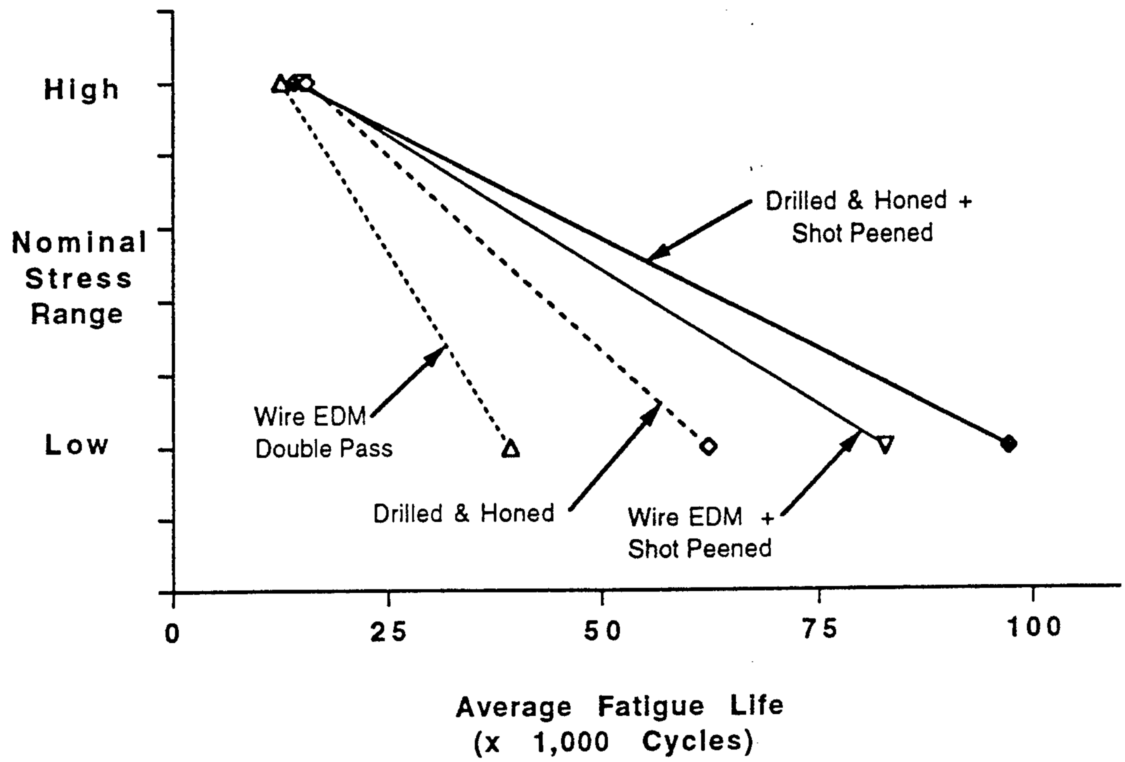


Figure 9. Wire EDM surface after glass-bead cleaning (magnification 500X)



Low Nominal Stress Range = 11.7 to 117 Ksi
High Nominal Stress Range = 17.0 to 170 Ksi
Stress Concentration Factor: 1.62

Figure 10. Nominal stress range versus total specimen fatigue life (Comparison of shot peened and unpeened surfaces)

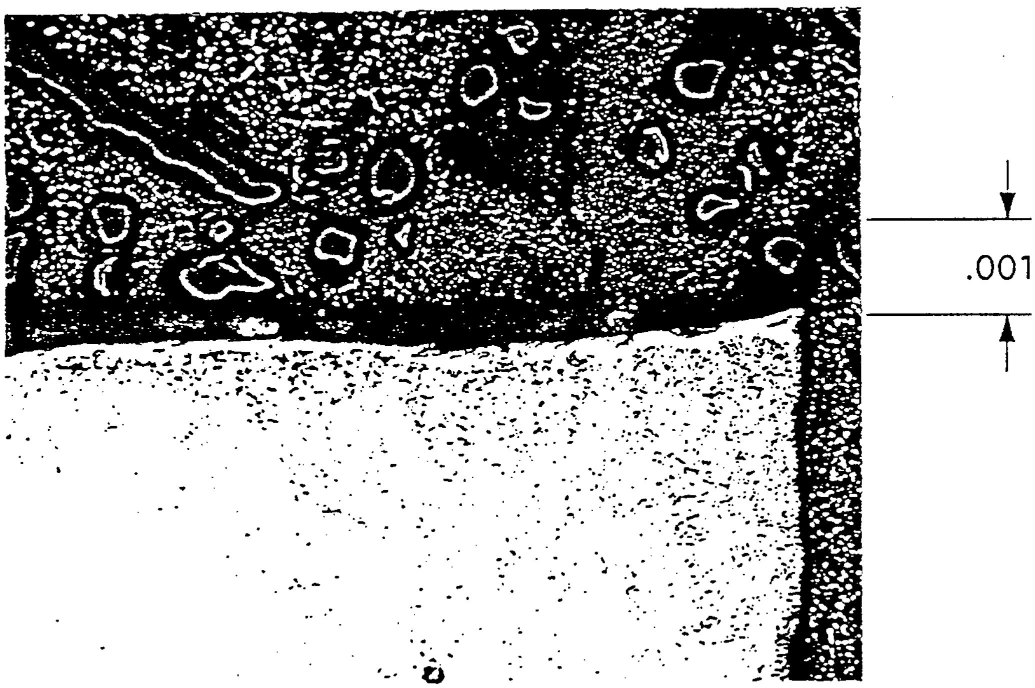


Figure 11. Wire EDM surface after steel shot peening (magnification 500X)

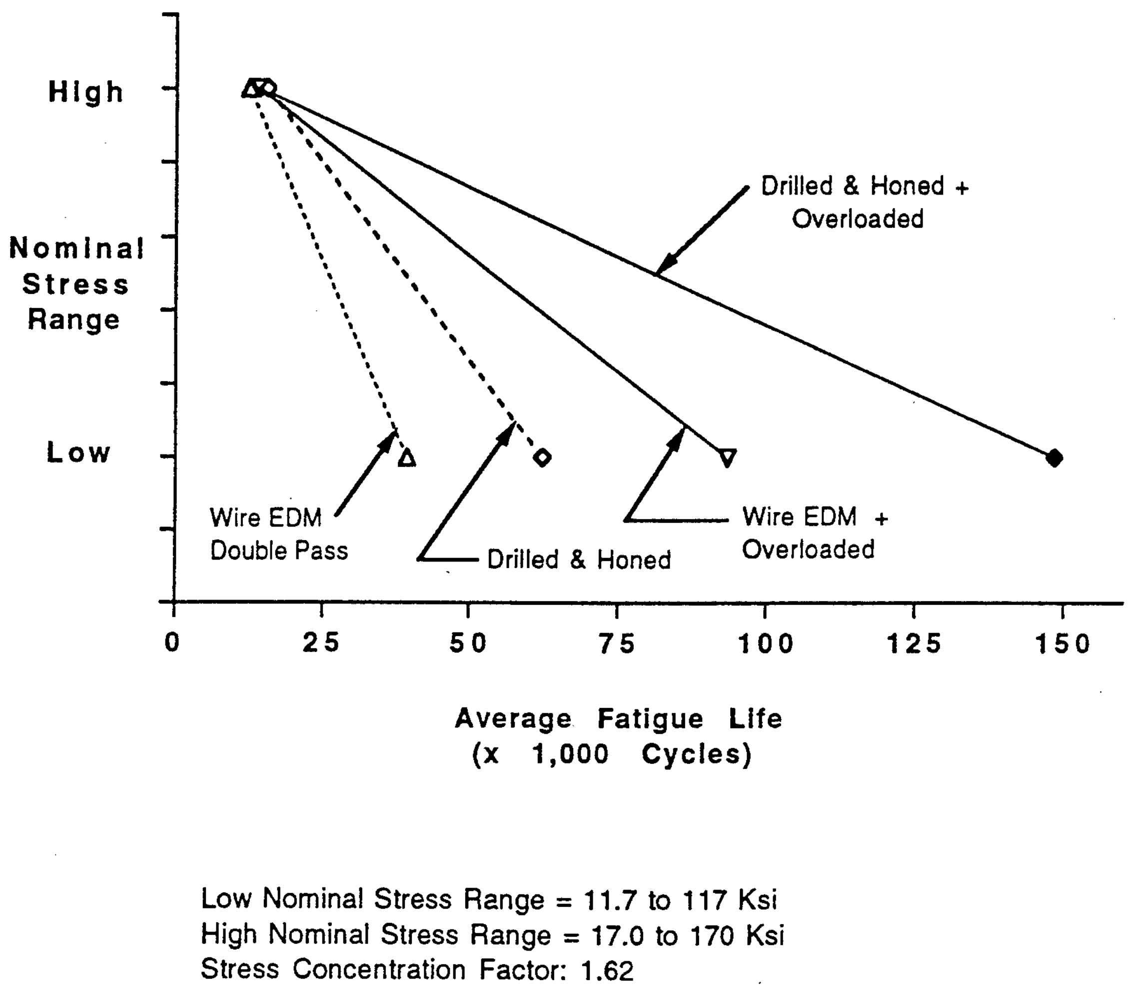


Figure 12. Nominal stress range versus total specimen fatigue life (Comparison of overloaded and non-overloaded surfaces)

TECHNICAL REPORT INTERNAL DISTRIBUTION LIST

	NO. OF COPIES
CHIEF, DEVELOPMENT ENGINEERING DIVISION	
ATTN: AMSTA-AR-CCB-DA	1
-DB	1
-DC	1
-DD	1
-DE	1
CHIEF, ENGINEERING DIVISION	
ATTN: AMSTA-AR-CCB-E	1
-EA	1
-EB	1
-EC	1
CHIEF, TECHNOLOGY DIVISION	
ATTN: AMSTA-AR-CCB-T	2
-TA	1
-TB	1
-TC	1
TECHNICAL LIBRARY	
ATTN: AMSTA-AR-CCB-O	5
TECHNICAL PUBLICATIONS & EDITING SECTION	
ATTN: AMSTA-AR-CCB-O	3
OPERATIONS DIRECTORATE	
ATTN: SIOWV-ODP-P	1
DIRECTOR, PROCUREMENT & CONTRACTING DIRECTORATE	
ATTN: SIOWV-PP	1
DIRECTOR, PRODUCT ASSURANCE & TEST DIRECTORATE	
ATTN: SIOWV-QA	1

NOTE: PLEASE NOTIFY DIRECTOR, BENÉT LABORATORIES, ATTN: AMSTA-AR-CCB-O OF ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST

	NO. OF COPIES
ASST SEC OF THE ARMY RESEARCH AND DEVELOPMENT ATTN: DEPT FOR SCI AND TECH THE PENTAGON WASHINGTON, D.C. 20310-0103	1
DEFENSE TECHNICAL INFO CENTER ATTN: DTIC-OCP (ACQUISITIONS) 8725 JOHN J. KINGMAN ROAD STE 0944 FT. BELVOIR, VA 22060-6218	2
COMMANDER U.S. ARMY ARDEC	
ATTN: AMSTA-AR-AEE, BLDG. 3022	1
AMSTA-AR-AES, BLDG. 321	1
AMSTA-AR-AET-O, BLDG. 183	1
AMSTA-AR-FSA, BLDG. 354	1
AMSTA-AR-FSM-E	1
AMSTA-AR-FSS-D, BLDG. 94	1
AMSTA-AR-IMC, BLDG. 59	2
PICATINNY ARSENAL, NJ 07806-5000	
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-DD-T, BLDG. 305 ABERDEEN PROVING GROUND, MD 21005-5066	1
DIRECTOR U.S. ARMY RESEARCH LABORATORY ATTN: AMSRL-WT-PD (DR. B. BURNS) ABERDEEN PROVING GROUND, MD 21005-5066	1
DIRECTOR U.S. MATERIEL SYSTEMS ANALYSIS ACTV ATTN: AMXSY-MP ABERDEEN PROVING GROUND, MD 21005-5071	1
COMMANDER ROCK ISLAND ARSENAL ATTN: SMCRI-SEM ROCK ISLAND, IL 61299-5001	1
MIAC/CINDAS PURDUE UNIVERSITY 2595 YEAGER ROAD WEST LAFAYETTE, IN 47906-1398	1
COMMANDER U.S. ARMY TANK-AUTMV R&D COMMAND ATTN: AMSTA-DDL (TECH LIBRARY) WARREN, MI 48397-5000	1
COMMANDER U.S. MILITARY ACADEMY ATTN: DEPARTMENT OF MECHANICS WEST POINT, NY 10966-1792	1
U.S. ARMY MISSILE COMMAND REDSTONE SCIENTIFIC INFO CENTER ATTN: AMSMI-RD-CS-R/DOCUMENTS BLDG. 4484 REDSTONE ARSENAL, AL 35898-5241	2
COMMANDER U.S. ARMY FOREIGN SCI & TECH CENTER ATTN: DRXST-SD 220 7TH STREET, N.E. CHARLOTTESVILLE, VA 22901	1
COMMANDER U.S. ARMY LABCOM, ISA ATTN: SLCIS-IM-TL 2800 POWER MILL ROAD ADELPHI, MD 20783-1145	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, BENÉT LABORATORIES, CCAC, U.S. ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND, AMSTA-AR-CCB-O, WATERVLIET, NY 12189-4050 OF ADDRESS CHANGES.

TECHNICAL REPORT EXTERNAL DISTRIBUTION LIST (CONT'D)

	NO. OF COPIES
COMMANDER U.S. ARMY RESEARCH OFFICE ATTN: CHIEF, IPO P.O. BOX 12211 RESEARCH TRIANGLE PARK, NC 27709-2211	1
DIRECTOR U.S. NAVAL RESEARCH LABORATORY ATTN: MATERIALS SCI & TECH DIV WASHINGTON, D.C. 20375	1
WRIGHT LABORATORY ARMAMENT DIRECTORATE ATTN: WL/MNM EGLIN AFB, FL 32542-6810	1
WRIGHT LABORATORY ARMAMENT DIRECTORATE ATTN: WL/MNMF EGLIN AFB, FL 32542-6810	1

NOTE: PLEASE NOTIFY COMMANDER, ARMAMENT RESEARCH, DEVELOPMENT, AND ENGINEERING CENTER, BENÉT LABORATORIES, CCAC, U.S. ARMY TANK-AUTOMOTIVE AND ARMAMENTS COMMAND, AMSTA-AR-CCB-O, WATERVLIET, NY 12189-4050 OF ADDRESS CHANGES.